Level 1 – Dive Medicine
Cardiac Issues and Diving

- May 12, 2026
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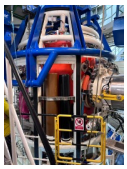
Objectives:



- Illustrate the importance of Cardiovascular Assessment
- Physiological changes of water immersion
- Brief review of EKG assessment
- Review use of exercise stress testing and investigations for the working diver
- Common cardiac conditions as they pertain to diving

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Int Marit Health
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www.intmarhealth.pl
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REVIEW ARTICLE

Medical assessment of fitness to dive. Part II

Jarosław Krzyżak[1], Krzysztof Korzeniewski[2, 3]

- The task of a dive doctor performing a diving health assessment is to disqualify each person who has medical contraindications to scuba diving, using their own experience and the recommended medical guidelines for assessing a person's fitness to dive. A preliminary health assessment for commercial divers must be very careful. Disqualification from scuba diving before the training starts will be less stressful for a candidate than disqualification shortly after the completion of training or at the beginning of a career.

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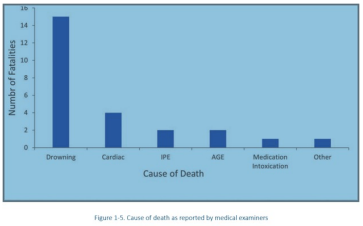

Figure 1-5. Cause of death as reported by medical examiners

What do divers die from?

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Age and Sex Distribution of Diving Fatalities

- 80% Male
- 67% were > 50 years of age

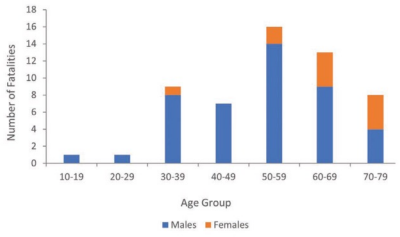

Figure 1-2. Age and sex distribution of reported fatal scuba accidents worldwide in 2018.

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Assessment of Cardiac Risk is key?

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History is key

Table 1. Cardiovascular Causes of Sudden Death in Young Athletes

Hypertrophic cardiomyopathy
Coronary artery anomalies
Commotio cordis (i.e., blunt trauma to the chest causing ventricular fibrillation)
Left ventricular hypertrophy
Myocarditis
Marfan syndrome (i.e., aortic root dilatation, aneurysm and subsequent rupture)
Arrhythmogenic right ventricular cardiomyopathy
Tunneled coronary artery
Aortic stenosis
Dilated cardiomyopathy
Myxomatous mitral valve degeneration
Mitral valve prolapse
Drug abuse
Long QT syndrome
Cardiac sarcoidosis
Brugada syndrome (a genetic disorder of myocardial sodium ion channels)

NOTE: Causes are listed in descending order of prevalence.
Information from references 2 and 4.

- Smoking
- High Cholesterol
- Diabetes
- Obesity
- Sedentary Lifestyle
- Murmurs
- Peripheral Vascular Disease*
- Family history
  - Syncope
  - Sudden death
  - ARVC

- Mountain biking uphill vigorous – 14 METS
- General Mountain biking – 8.5 METS
- Crab fishing – 4.5 METS
- Washing car – 3.5 METS
- Carrying groceries upstairs – 7.5 METS
- Child-care dressing/bathing child 2-3 METS
- Mowing grass push mower – 6 METS
- Shoveling snow – 5.3-7.5 METS

2011 Compendium of Physical Activities

Volume 75, Number 7 • April 1, 2007 www.aafp.org/afp

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History Questions

Table 3. Cardiovascular Screening Questions for the Athletic Preparticipation Examination

Have you ever passed out or nearly passed out during or after exercise?
Have you ever had discomfort, pain, or pressure in your chest during exercise?
Does your heart race or skip beats during exercise?
Has a doctor ever told you that you have high blood pressure, high cholesterol, a heart murmur, or a heart infection?
Has a doctor ever ordered a test for your heart (e.g., electrocardiography, echocardiography)?
Has anyone in your family died for no apparent reason?
Does anyone in your family have a heart problem?
Has anyone in your family died of heart problems or of sudden death before 50 years of age?
Does anyone in your family have Marfan syndrome?

Adapted with permission from Preparticipation Physical Evaluation. 3rd ed. Minneapolis, Minn.: McGraw-Hill/Physician and Sportsmedicine, 2005:19.

Volume 75, Number 7 • April 1, 2007 www.aafp.org/afp

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Common Hereditary Cardiac Diseases

- Hypertrophic Cardiomyopathy
- Dilated Cardiomyopathy
- Arrhythmogenic Right Ventricular Cardiomyopathy
- Familial Hypercholesterolemia
- Long QT syndrome
- Brugada syndrome
- Familial Amyloidosis
- Marfan syndrome

https://www.123rf.com/photo_197111551_cartoon-illustration-of-a-family-tree.html

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Shortness of Breath

- Anxiety related
- Cardiac verses Respiratory Origin
- Consider more investigations in this situation
- This is a Giant RED FLAG

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Ontario Code for Medical Examination of Divers

regulation 629/94 (Diving Operations) OHSA

- Shall consider: age, **physical fitness**, medications and underlying conditions, smoking, disability and **functional loss**, obesity
- Cardiovascular system including: ischemic heart disease, dysrhythmia, pacemaker, PFO, valvular heart disease, blood pressure and peripheral circulation
- Contraindications listed: symptomatic ischemic heart disease, conventional coronary artery bypass surgery, dysrhythmia that may cause incapacity in water, atrial or ventricular septal defects, aortic or mitral stenosis, coarctation, varicose veins with impaired perfusion

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Ontario Code for Medical Examination of Divers

regulation 629/94 (Diving Operations) OHSA
Same as **CSA Z275.2:20**

- Electrocardiogram
  - If < 40 years – initial medical resting EKG
  - At 40 years – Exercise EKG
  - > 40 years – resting EKG every 2 years until age 50
  - At 50 years – Exercise EKG annually

- **EKG ordered as clinically indicated**

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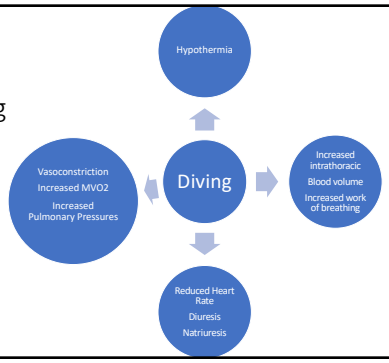
Changes with Diving



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Issues at hand – CO= HR x SV

- We need to have adequate cardiac output to meet demands of the underwater environment
- Metabolic demands of swimming
- Is there a reserve capacity for emergencies?
- Do we have enough pump to maintain Stroke Volume?
- Do we have a stable rhythm to maintain cardiac output
- Afterload goes up
- Preload goes up

12-3 METS ideal
10 METS is good
6 METS bare minimum to start with goal to increase

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Association of Diving Contractors International, Inc.

"Chronic Conditions requiring continuous control by medication that increases risks in diving"

Screen for history of cardiac arrest, impairment in oxygen transport or anything that would impair effective underwater work

EKG initial baseline, annually after 35 or as indicated

EKG stress test medically indicated or when FRS > 10%

Framingham Risk Score baseline and annually after 35

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Diving and Hyperbaric Medicine Volume 50 No. 3 September 2020

Specific Cardiac Questions

- Do you have any known heart disease, or have you ever consulted a cardiologist (specialist heart doctor)?
- Is there any family history of heart disease or diabetes?
- Is there any family history of sudden death at a young age? Single vehicle accidents? Drowning?
- Are you ever aware of a racing or irregularly beating heart, or any other known problem with your heart beat?
- Have you ever had giddiness, light-headedness or periods of unconsciousness, whether or not associated with exercise?
- Do you have a pacemaker or implanted defibrillator?
- Have you ever had an operation on the heart including any placement of stents?
- Do you ever get discomfort in your chest on exertion (angina)?
- Do you get very short of breath on exertion (out of proportion to the exercise, or before your legs get tired)?
- Have you ever been short of breath lying down or woken from sleep with breathlessness?

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Unfit for Diving -

- Untreated and/or symptomatic coronary artery disease
- Left ventricular dysfunction of any cause (would need to recover to EF >50% with good exercise capacity and underlying causes treated + Cardiology review)
- Hypertrophic Cardiomyopathy*
- Congestive Heart Failure
- Complex congenital disease*
- Implantable defibrillator
- Pulmonary Hypertension
- Long QT syndrome or other arrhythmia inducing ion channelopathies
- Paroxysmal arrhythmias causing unconsciousness or impaired exercise tolerance
- Poor exercise capacity (cardiac origin)
- Moderate to severe valvular lesions
- Recurrent syncope

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Other Questions?

- Hypertension?
- Rheumatic fever or heart valve problems?
- Hypercholesterolemia?
- Immersion Pulmonary Edema?
- Heart failure, or heart muscle problems, including cardiomyopathy or CAD?
- Hole in heart or other congenital disease?
- Blood clots to legs or lungs?
- Stroke?
- Have you ever failed or had an issue with diving medical in the past?*

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Cardiac Risk Conditions

Severe Risk
- Untreated coronary disease
- Dilated or obstructive cardiomyopathy
- Heart failure
- Pulmonary hypertension
- Long QT syndrome
- Channelopathies
- Paroxysmal arrhythmias
- Complex congenital disease
- Atrial septal defect
- ICD
- Multiple Episodes of Immersion Pulmonary Edema
- Poor Exercise capacity Cardiac Origin

Relative Risk
- Treated Coronary Disease
- Age > 45, smoker, htn, +ve family hx, high cholesterol may need to investigate
- History of dysrhythmias requiring medication for suppression
- Mild valvular lesions (need periodic re-evaluation)
- Cardiac prostheses or arrhythmias requiring anticoagulation
- Pacemakers
- Single episode of immersion pulmonary edema
- Left ventricular hypertrophy
- Marfan syndrome or connective tissue disorder (severe risk if history of dissection)

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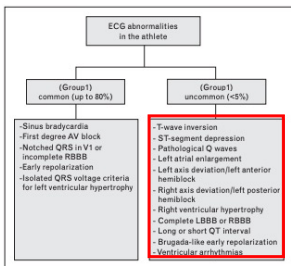
REVIEW

Curr Opin Cardiol 2012, 27:41–48

Sudden cardiac death in athletes: what is the role of screening?

- Age related sudden death associated with sports
- Age > 35 – Coronary Atherosclerotic Disease
- Age < 35:
  - Hypertrophic Cardiomyopathy
  - Arrhythmogenic right-ventricular dysplasia
  - Congenital Coronary Anomalies
  - Myocarditis
  - Aortic Rupture
  - Valvular Disease
  - Pre-excitation syndromes
  - Cardiac conduction diseases
  - Ion channel diseases
  - Congenital heart diseases



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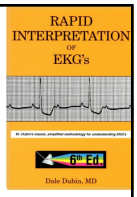
Quick EKG Interpretation



- 1. Rate
  - R wave on bold line
  - 300,150,100,75,60,50
- 2. Rhythm
  - Regular or Irregular, P-wave with RS, PR constant
- 3. Axis
  - Leads I and aVF, + 1 & + aVF Normal, +1 & - aVF Left axis, - 1 and + aVF Right axis
- 4. Hypertrophy
  - Tall R V1 = RVH, Deep S in V1 and tall R V5 or V6 > 35 mm = LVH
  - Look at P waves in 2 and V1 for atrial enlargement
- 5. Ischemia
  - Ischemia – T wave inversion, ST elevation, pathologic Q waves

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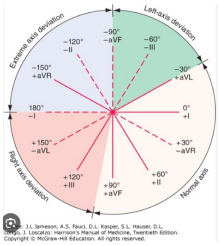
https://litfl.com/ecg-axis-interpretation/#:~:text=Cardiac%20axis%20represents%20the%20sum,axis%2C%20which%20are%20summarized%20below:

Summary Table:

Lead 1	Lead aVF	Quadrant	Axis
POSITIVE	POSITIVE		**Normal Axis** (0 to +90°)
POSITIVE	NEGATIVE		****Possible LAD** (0 to -90°)
NEGATIVE	POSITIVE		**RAD** (+90° to 180°)
NEGATIVE	NEGATIVE		**Extreme Axis** (-90° to 180°)

*Note: ****Possible LAD** can be further evaluated using **Lead II** as detailed in method 2 below...*



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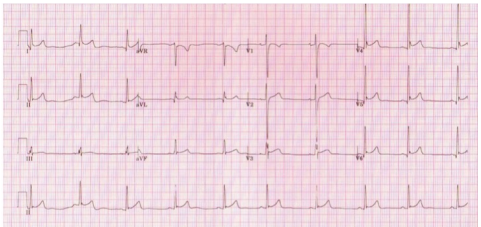
Good or Bad?



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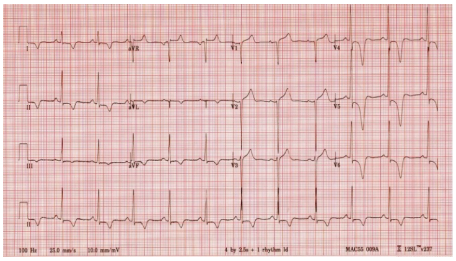
Good or Bad?



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Prolonged QT Syndrome

Males QTc ≥ 470 ms (460-469 borderline)
Females QTc ≥ 480 ms (460-479 borderline)

- Romano-Ward syndrome
- Jervell and Lange-Nielsen Syndrome
- Acquired:
  - Macrolides
  - Antifungals
  - Non-potassium sparing diuretics
  - Antidepressants/antipsychotics
  - Anti-emetics
- Hypothermia
- Hypocalcemia
- Hypomagnesemia
- Hypokalemia
- Pheochromocytoma
- Intracerebral bleed
- Hypothyroidism

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Risk Factors

- Hx Cardiac Arrest
- First degree relative with long QT
- Female on cardiac medication
- **Excessive vomiting or diarrhea**

- QUESTIONS??
- Personal history of **palpitations**, **syncope, pre-syncope**, or **seizures**
- Family history of unexplained sudden cardiac death at a young age, one-sided motor vehicle accident, drowning

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Where is the money for Cardiovascular assessment?

- History and Questions?
- Look for:
  - Obesity
  - Hypertension
  - Diabetes
  - Smoking
  - Hyperlipidemia
- 90% deaths over 40 years
- At minimum EKG
- Concerns for ischemia obtain an exercise stress test
- Ideal tolerate 13 METS (VO2 max of 45.5 ml/kg/min
- Structural Questions - echocardiography

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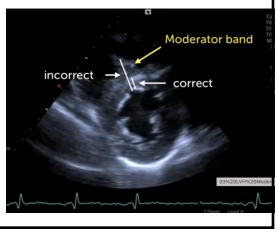
Comparative Study > Undersea Hyperb Med. 2014 Mar-Apr;41(2):127-33.

Prevalence of cardiomegaly and left ventricular hypertrophy in scuba diving and traffic accident victims

Petar J Denoble, Craig L Nelson, Shabbar I Ranapurwala, James L Caruso

- Frequently asymptomatic
- Independent predictor of sudden cardiac death
- 100 scuba deaths vs 178 traffic fatalities
- Heart mass 428.3± 100 and 387 ± 87 for controls
- LVWT 15 ± 3.5 divers and 14 ± 2.7 controls



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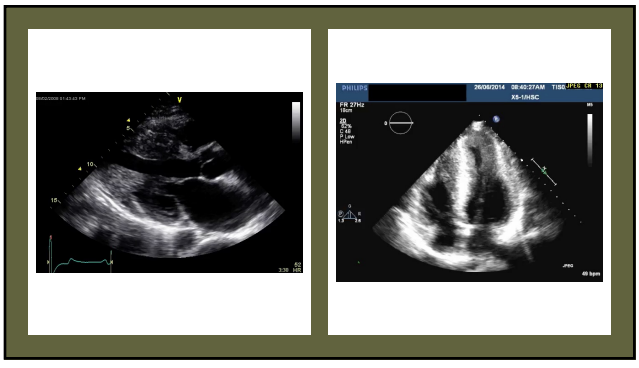

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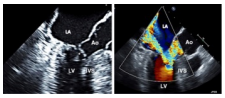
HCM

Hindieh, Waseem & Chan, Raymond & Rakowski, Harry. (2017). Complementary Role of Echocardiography and Cardiac Magnetic Resonance in Hypertrophic Cardiomyopathy. Current Cardiology Reports. 19. 10.1007/s11886-017-0897-z.

- 1 in 500
- Annual mortality 1-2%
- #1 cause of sudden death in young people
- Left ventricular hypertrophy in absence of inciting stimulus
- Most common pattern is asymmetrical thickening of the anterior interventricular septum – classically associated with systolic anterior motion of mitral valve and left ventricular outflow obstruction (25% of cases SAM)
- Less common patterns concentric 20%, apical 10%
- Histopathology hypertrophied myocytes, chaotic and disorganized fashion, intramural coronary arterioles are structurally abnormal with decreased cross-sectional liminal area and impaired vasodilatory response
- Many have no symptoms or only minor
- Result of family screening, detection of murmur or identification of abnormal EKG
- LVOT gradients, **dyspnea, fatigue, chest pain, and syncope**



https://litfl.com/hypertrophic-cardiomyopathy-hcm-ecg-library/

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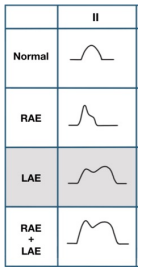
HCM EKG changes

- Left ventricular hypertrophy – S wave depth V1 + tallest R wave height in V5/6 > 35 mm
- Increased precordial voltages and non-secific ST segment and T-wave abnormalities
- Deep, narrow (dagger) Q waves in lateral (I, aVL, V5-6) +/- inferior (II, III, aVF) leads (Dagger septal Qs < 40 ms)
- May see LAE, short PR interval, delta waves
- Dysrhythmias: A fib, SVTs, PACs, PVCs, VT
- Giant precordial T-wave inversions in apical HCM



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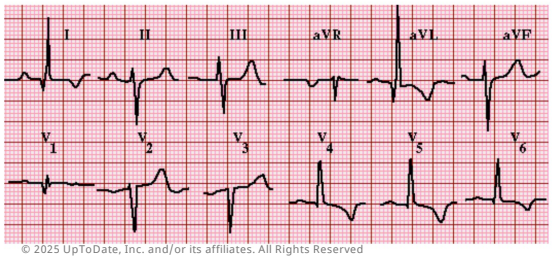
Left ventricular hypertrophy with strain pattern



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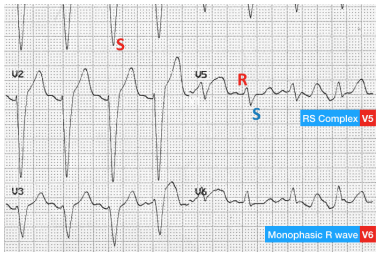
Left Bundle Branch Block



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LBBB

- QRS duration ≥ 120ms
- Dominant S wave V1
- Broad monophasic R wave in lateral leads (I, aVL, V5-6)
- Absence of Q waves in lateral leads
- Prolonged R wave peak time > 60 ms in leads V5-6 (more than 1.5 squares)
- Usually organic disease
- Aortic, stenosis, IHD, HTN,
- Dilated CM, Anterior MI, Digoxin Toxicity, Hyperkalemia, Lenegre-Lev disease

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Arrhythmogenic Right Ventricular Dysplasia

https://litfl.com/arrhythmogenic-right-ventricular-dysplasia-arvd/

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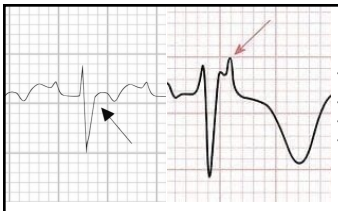

- 2nd most common cause of sudden cardiac death in young people (HOCM #1)
- 10% of sudden cardiac deaths in patients < 65
- Prevalence ~ 1 in 5000
- EKG : T wave inversion V1-3 in absence of RBBB (85%)
  Epsilon wave (specific 50%)
  Localized QRS widening V1-3 (>110ms)
  Prolonged S wave upstroke 55ms V1-3
  Ventricular ectopy of LBBB (>1000 PVCs/24 hrs)
  Paroxysmal VT with LBBB morphology

ARVD

https://litfl.com/arrhythmogenic-right-ventricular-dysplasia-arvd/

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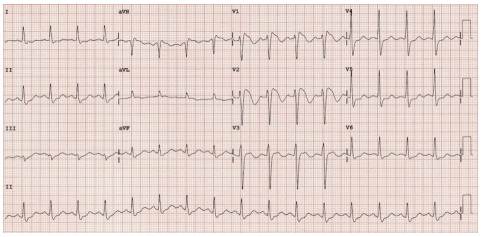

https://litfl.com/brugada-syndrome-ecg-library/

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Brugada Syndrome

- Cardiac sodium channel gene mutation, 60 describes mutations, 50% spontaneous, familial clusters and autosomal dominant inheritance
- High incidence of sudden death in patients with structurally normal hearts
- Mean age sudden death 41 years
- Definitive treatment is ICD
- **Coved ST elevation > 2 mm atleast 2 of V1-3 followed by negative T wave &**
- Documented VF or polymorphic VT, family history cardiac sudden death < 45 years, coved-type EKGs in family members, Inducibility of VT with electrical stimulation, Syncope, Nocturnal agonal respiration

https://litfl.com/brugada-syndrome-ecg-library/

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Cardiac Fitness

- Questionnaires: chest pain, shortness of breath, dizziness, palpitations, syncope
- Past medical history: obesity, hypertension, diabetes, smoking, hyperlipidiemia
- Physical examination – auscultation, blood pressure, other signs
- Echocardiogram
- Exercise scintigraphy
- Stress testing
- Electrophysiological studies

Pathologic murmurs

Associated arrhythmia

Associated left ventricular apical or right ventricular parasternal heave

Associated with abnormal jugular venous pulse; wide pulse pressure; or brisk, rapidly rising pulse or weak, slowly rising pulse

Change in intensity with physiologic maneuvers (especially if murmur becomes louder with Valsalva or squat-to-stand maneuvers)

Diastolic murmur

Family history of sudden death or cardiac disease

Long duration (mid- or late-peak or holosystolic murmur)

Loud murmur (grade 3 or more)

Other abnormal heart sounds (e.g., loud S_1, fixed or paradoxically split S_2, midsystolic click)

Presence of associated symptoms (e.g., chest pain, dyspnea on exertion, syncope)

Radiation to axilla or carotids

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(*Circulation*. 2012;126:e354-e471.)

Stress Test Pretest Probability

Table 9. Pretest Likelihood of CAD in Symptomatic Patients According to Age and Sex* (Combined Diamond/Forrester and CASS Data)

	Nonanginal Chest Pain		Atypical Angina		Typical Angina	
Age, y	Men	Women	Men	Women	Men	Women
30–39	4	2	34	12	76	26
40–49	13	3	51	22	87	55
50–59	20	7	65	31	93	73
60–69	27	14	72	51	94	86

CAD indicates coronary artery disease; and CASS, Coronary Artery Surgery Study.

* Each value represents the percent with significant CAD on catheterization.

Adapted from Forrester and Diamond.[52,73]

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CSA GROUP

CSA Z275.2:20
National Standard of Canada

Occupational safety code for diving operations

Guidelines are presented for EKG and Exercise Stress Testing
Other required investigations and consultations are as deemed appropriate

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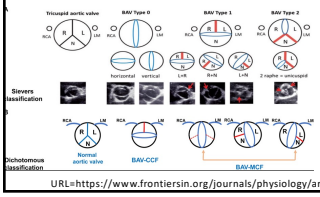
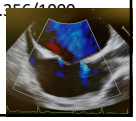
Most common Congenital Heart Lesions

- Ventricular Septal Defect 30%
- Bicuspid Aortic Valve in 0.5-2% of population
- Atrial Septal Defect - 1.441/1000 live births
- Patent Ductus Arteriosus - 1.004/1000 live births
- Pulmonary stenosis – 0.546/1000 live births
- Tetrology of Fallot – 0.356/1000 live births





URL=https://www.frontiersin.org/journals/physiology/articles/10.3389/fphys.2018.01921

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Diving and Hyperbaric Medicine Volume 50 No. 1 March 2020

Review articles

Diving with hypertension and antihypertensive drugs

Peter E Westerweel[1,2], Rienk Rienks[2,3,4,5], Ahmed Sakr[6], Adel Taher[6]

- 30-45% of population if affected
- Many recreational divers
- DAN USA data 24.6% of divers HTN
- Dutch divers 12% HTN on survey
  - 4.3% ACEI/ARB
  - 1.4% Diuretic
  - 1.8% CCB
  - 1% β-Blocker
- Optimal BP <120 mmHg systolic and < 80 mmHg diastolic
- Hypertension systolic ≥ 140 mmHg and/or diastolic ≥ 90 mmHg (Office)
- Home measurement ≥ 135/85 mmHg validated device
- 24-hour average ≥ 130/80 mmHg, average daytime ambulatory ≥ 135/85 and/or ≥ 120/70 mmHg nighttime

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Diving and Hyperbaric Medicine Volume 50 No. 1 March 2020

Antihypertensives

Review articles

Diving with hypertension and antihypertensive drugs

Peter E Westerweel[1,2], Rienk Rienks[2,3,4,5], Ahmed Sakr[6], Adel Taher[6]

- ACEI
  - Dry cough
- ARBs
  - No real risk
- Calcium channel blockers – safe for diving
  - Orthostatic hypotension
- α-blockers – may lead to dizziness or drowsiness (if drink too little), also ? Faster cooling
- β-blockers – avoid extreme exertion, may reduce exercise tolerance, ?IPE*
- Diuretics – synergistic with immersion induced diuresis, may lead to further plasma volume depletion

Better

Worser

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Why we worry?

Canadian Journal of Cardiology 36 (2020) 596–624

Guidelines

Hypertension Canada's 2020 Comprehensive Guidelines for the Prevention, Diagnosis, Risk Assessment, and Treatment of Hypertension in Adults and Children

Table 2. Examples of target organ damage

- Cerebrovascular disease
  - Stroke
    - Ischemic stroke and transient ischemic attack
    - Intracerebral hemorrhage
    - Aneurysmal subarachnoid hemorrhage
  - Dementia
    - Vascular dementia
    - Mixed vascular dementia and dementia of the Alzheimer's type
- Hypertensive retinopathy
- Left ventricular dysfunction
- Left ventricular hypertrophy
- Heart failure
- Coronary artery disease
  - Myocardial infarction
  - Angina pectoris
  - Acute coronary syndromes
- Renal disease
  - Chronic kidney disease (GFR < 60 mL/min/1.73 m^2)
  - Albuminuria
- Peripheral artery disease
  - Intermittent claudication

GFR, glomerular filtration rate.

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Table 3. Examples of key cardiovascular risk factors for atherosclerosis

- History of clinically overt atherosclerotic disease indicates a very high risk for a recurrent atherosclerotic event (eg, peripheral arterial disease, previous stroke or transient ischemic attack)
- Nonmodifiable
  - Age ≥ 55 years
  - Male sex
  - Family history of premature cardiovascular disease (age < 55 in men and < 65 in women)
- Modifiable
  - Sedentary lifestyle
  - Poor dietary habits
  - Abdominal obesity
  - Dysglycemia
  - Smoking
  - Dyslipidemia
  - Stress
  - Nonadherence

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History of Myocardial Infarction or Coronary Stenting

Off 6-12 months

Fitness then assessed by exercise tolerance

If reduced ejection fraction may be predisposed to acute pulmonary edema from immersion

- Congestive heart failure patients are not fit for diving
- Need to be free of anginal symptoms, good exercise tolerance, no arrythmias
- Some suggest annual echocardiography to ensure good function and exercise stress test

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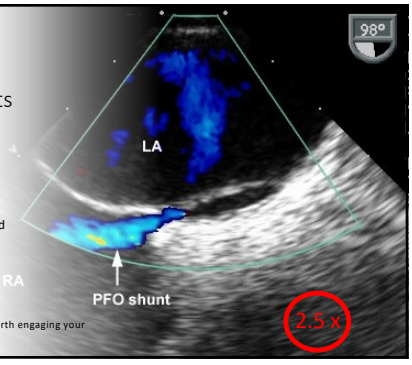
Patent Foramen Ovale or Atrial Septal Wall Defects

- Increase the risk for DCS
- May allow microbubbles to enter systemic circulation by bypassing the lungs
- Historically a Transesophageal echocardiogram was suggested to screen for a PFO
- TTE in appropriate lab acceptable

There is a spectrum of PFO – it is worth engaging your Cardiology colleague here



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> J Invasive Cardiol. 2012 Jun;24(6):274-7.

Percutaneous closure of patent foramen ovale and valvular function -- effect of the amplatzer occluder

Nazmi Krasniqi [1], Janice Roth, Patrick T Siegrist, Stefan Toggweiler, Christiane Gruner, Matthias Greutmann, Felix C Tanner, Thomas F Lüscher, Roberto Corti

- 6.2% patients had significant shunt > 20 bubbles post
- 86.4% 25 mm Amplatzer
- 13.6% 35 mm Amplatzer
- 3% transient atrial fibrillation
- 0.6% permanent atrial fibrillation
- AR 16% pre, 22% post, 7% new - 1.6% worsened, 2 patients AR resolved
- MR 44% pre, 55% post, < 1% worsened, 16% new, 10 patients MR resolved
- TR 59% pre, 81% post, 25% new, disappeared 5 patients

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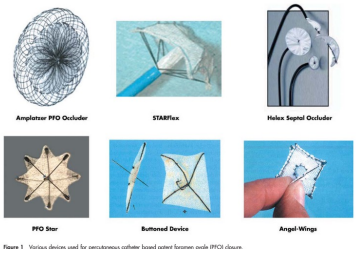
PFO Closure Devices



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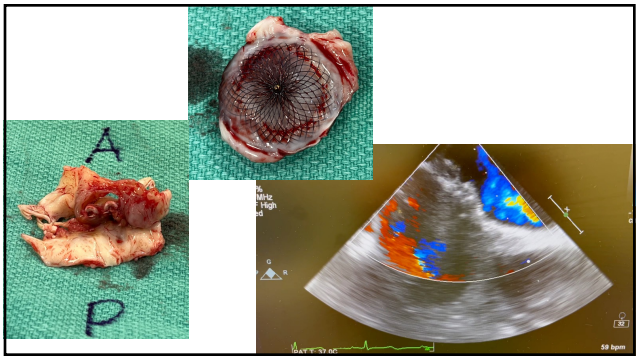

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PFO agitated bubble study

- Agitated saline injection into an antecubital vein and look at number of bubbles seen in the left atrium after 3 cardiac cycles

Elimination of Right to Left Shunt
92.4% at 6 months
95.5% at one year
99.3% at two years
100% at five years

- International Consensus Criteria
- Grade 0 – No bubbles
- Grade I – 1 to 9 bubbles
- Grade II – 10-20 bubbles
- Grade III - >20 bubbles

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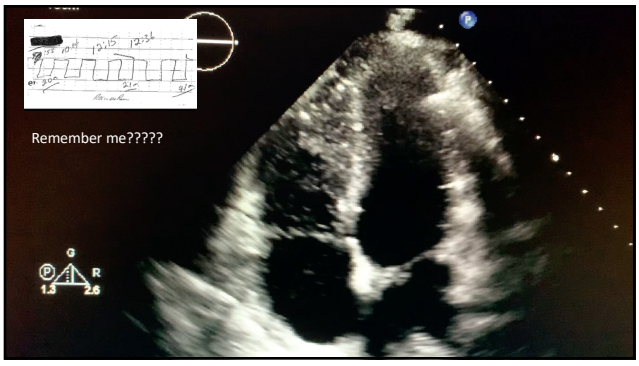

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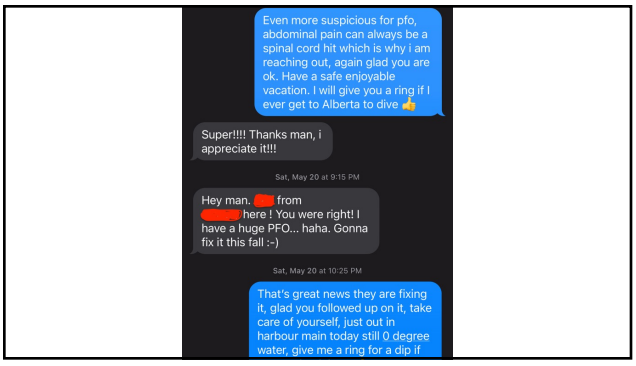

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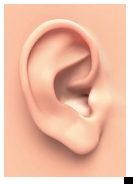
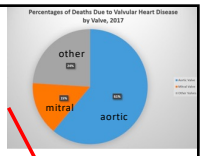
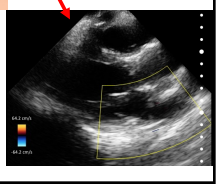
Valvulopathy

- If you can hear a heart murmur
- Regurgitant lesions may respond poorly to the increased afterload of immersion
- Look for resulting chamber enlargement
- Diastolic always pathologic







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Bicuspid Aortic Valves

- Common anomaly 0.5-2% of population
- Various phenotypes true bicuspids and fusion of 2 of 3 leaflets
- 30-40 years vs ≥ 50 years

- Male 3:1 Female
- Variable course
  - Asymptomatic
  - Isolated regurgitation
  - Isolated aortic stenosis
  - Infective endocarditis 2-5%*
  - Aortic Dilation
  - Associated with Coarctation/PDA

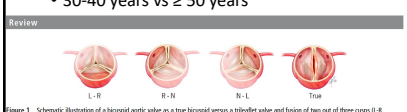

Figure 1 Schematic illustration of a bicuspid aortic valve as a true bicuspid versus a trileaflet valve and fusion of two out of three cusps (L-R suggesting fusion of left and right cusps, R-N suggesting fusion of right and non-coronary cusps and N-L suggesting fusion of left and non-coronary cusps).

Figure 4 Schematic illustration of different aortic dilation patterns noted in patients with bicuspid aortic valve.

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Normal Valve Sizes

- Aortic and Pulmonic Valves
  - 2.5-4 cm^2
- Mitral valve
  - 4-6 cm^2
- Tricuspid valve
  - 9-11 cm^2

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What to do with Valvular stenosis?

Circulation
Volume 143, Issue 5, 2 February 2021; Pages e72-e227
https://doi.org/10.1161/CIR.0000000000000923

Grading severity of mitral stenosis

	Mild	Moderate	Severe
Mean gradient (mm Hg)	<5	5–10	>10
Pulmonary artery systolic pressure (mm Hg)	<30	30–50	>50
Valve area (cm^2)	>1.5	1.0–1.5	<1.0

Classification	*Transaortic velocity (m per second)*	*Mean pressure gradient (mm Hg)*	*Aortic valve area (cm^2)*
Normal	< 2.0	< 10	3.0 to 4.0
Mild	2.0 to 2.9	10 to 19	1.5 to 2.9
Moderate	3.0 to 3.9	20 to 39	1.0 to 1.4
Severe	≥ 4.0	≥ 40	< 1.0

Information from reference 20.

Severe Tricuspid Stenosis < 1.0 cm2
Pulmonic stenosis velocity > 4 m/s or Gradient > 60 mmHg

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Valvular lesion	Common ECG findings	Common CXR findings
Aortic stenosis	Left ventricular hypertrophy (LVH)	Enlarged cardiac silhouette, aortic calcifications, potential pulmonary edema
Aortic regurgitation (chronic)	LVH, left heart strain	May have no acute findings
Aortic regurgitation (acute)	May have no acute findings	Widened mediastinum, enlarged cardiac silhouette
Mitral stenosis	P mitrale due to LA enlargement, potential AF	May have no acute findings
Mitral regurgitation (chronic)	P mitrale due to LA enlargement, potential AF	Enlarged LA and LV
Mitral regurgitation (acute)	No specific changes related to valvular disease, though may indicate underlying etiology (e.g., STEMI)	Severe pulmonary edema

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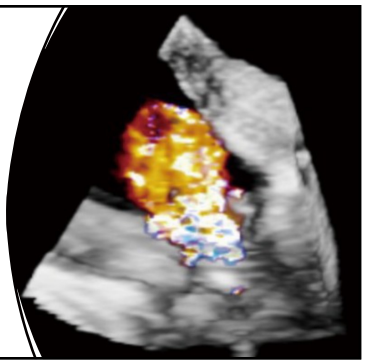
Severe Tricuspid Regurgitation

- Dilated RV and RA
- Clinically – elevated venous pressure, dyspnea on exertion, fatigue, ascites, edema
- HISTORY



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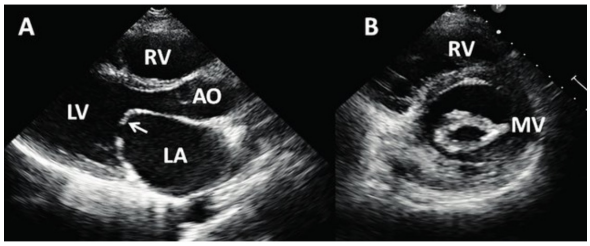
Mitral Stenosis



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Mitral Valve Prolapse

- Common disease, ≧ 2 mm of atrial displacement of leaflet, thickened leaflets ≧ 5 mm
- Female preponderance
- 0.6-3% of population
- May have no Mitral regurgitation
- Most common cause of primary moderate or severe MR
- Some patients develop atrial fibrillation, risk of ventricular arrhythmias and sudden cardiac death (rare)
- Nonejection click
- **Asymptomatic mitral valve prolapse (5-10% of population) may be declared fit – no palpitations, arrythmias or syncope**

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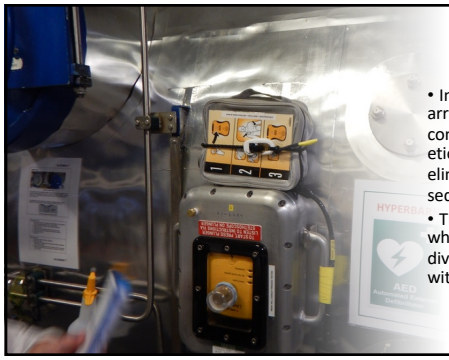

- In general history of arrhythmia is a NO go for commercial diver unless etiology is found and eliminated with no sequelae
- There may be cases where a recreational diver may be approved with education

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Pacemakers and Implantable Cardiac Defibrillators

- Cardiac Arrhythmias pose risk of loss of consciousness ⇨ drowning
- If associated with coronary disease, myocardial dysfunction, or cardiomyopathy? 👋
- If worse under stress? Causes lightheadedness or pain?👋
- Atrial Fibrillation – if investigated, rate controlled and asymptomatic under stress is compatible with diving
- Pacemaker if in good working order is compatible with diving (not for anti-tachycardia functions)
- ICDs – are absolute contraindication to diving

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- Pacemaker patient free of: syncope, dizziness, chest pain, inappropriate dyspnea
- Limited to SA or AV node disease
- Appropriate response to exercise (220-age in years) and 9 minutes or stage 3 of Bruce protocol
- Prefer resin filled model
- Hyperbaric tested
- Depth limit 10 metres less than tested rating

UHM 2006 Vol 33.5:349

Manufacturer	Pacers Approved	Max Pressure (atm abs)	ICDs Approved	Max Pressure (atm abs)
Medtronics	Thera-I, Elite, Prodigy	2.5	Marquis Gem	Not disclosed
Guidant	Insignia+, Pulsar, Pulsar-Max LH, Discovery LH, Meridian, Vertas II, Intrln II	4.9	Contak Renewal 3,4 Ventak Prism III	4.9
St. Jude Medical	All "current" models	8.0	Photon Micro (V194,V232,V239(IV) Epic (V197,V233,V235) Epic+ (V196,V236,V239) Atlas (V199,V240); Epic+III (V337,V338) Atlas+HF (V340,V343)	3.0
Biotronik, Inc	Philos UH, Pyrios, Cylos, Actros	3.0	Lumos, Lumos, Nelos, Belos	3.0
ELA Medical	All	4.0	9201, 614, 615, 624, 625	1.5

Cardiac pacing under hyperbaric conditions. Annals Thoracic Surg 1983; 36: 66-8

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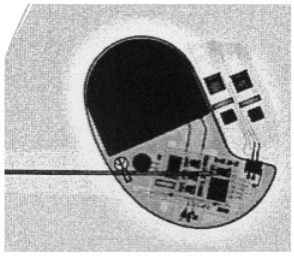
Pacemaker Deformation

- Significant from 30 m to 60 m in 65% of tested pacemakers
- Deformation occurred over the electronic part, battery part not significantly altered
- No functional impact
- Good water tightness
- No deformations up to 30m



1 *x* Ray radiography of a pacemaker. Note maximal deformat
ad at the tip of the needle.

Med 2008;**42**:212–216. doi:10.1136/bjsm.2007.039552

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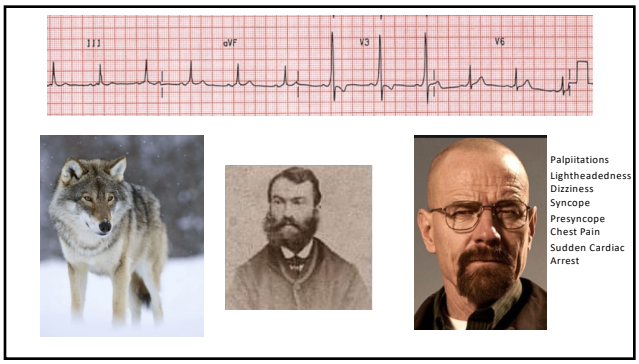

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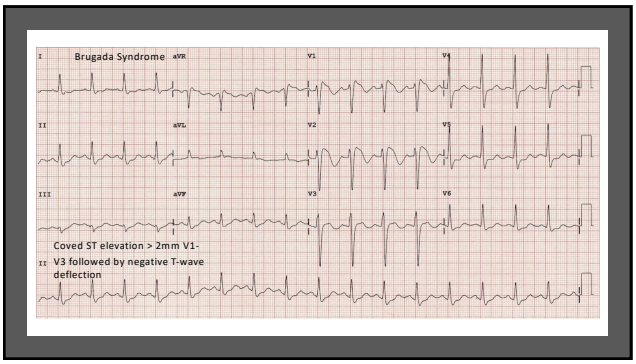

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Takotsubo's

Case report

A case report of cerebral arterial gas embolism (CAGE) associated with Takotsubo cardiomyopathy

Diving and Hyperbaric Medicine Volume 49 No. 3 September 2019

- 1990s described in Japan "stress cardiomyopathy"
- Up to 2% of patients presenting with acute MI
- More common in women than men, usually older adults
- 4% recurrence rate
- Usual recovery in 3 weeks
- May follow sympathetic stimulation
- Up to 1/3 may involve Right and Left ventricles
- 20% variable recurrence pathway
- Most commonly apical 82.2%, midventricular 17.8%

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Deep Vein Thrombosis

- Can not dive until full mobilization and exercise tolerance
- After pulmonary embolism??? Again, go to symptoms
- **CAN NOT DIVE ON ANTICOAGULATION**
- Want to ensure there is no right heart strain

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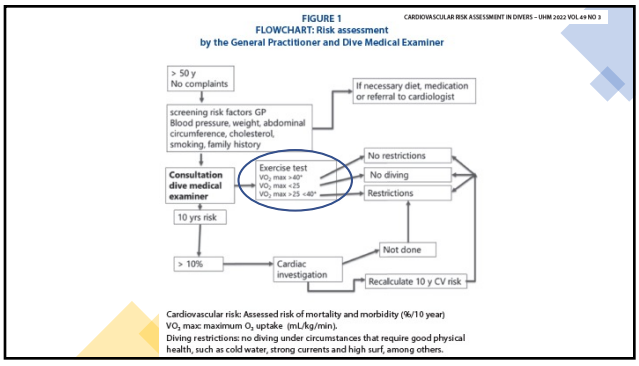

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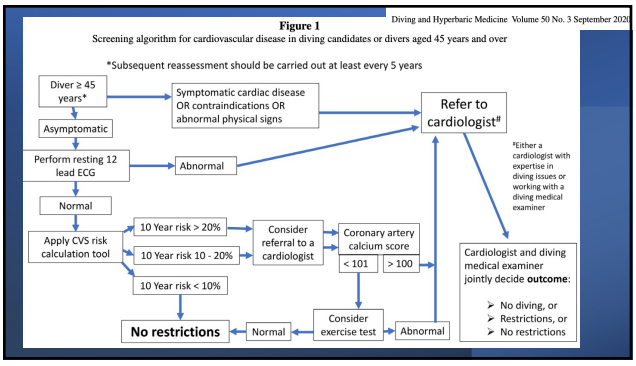

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Coronary Calcium Score

Calcium Score	Presence of CAD
0	No evidence of CAD
1-10	Minimal evidence of CAD
11-100	Mild evidence of CAD
101-400	Moderate evidence of CAD
Over 400	Extensive evidence of CAD

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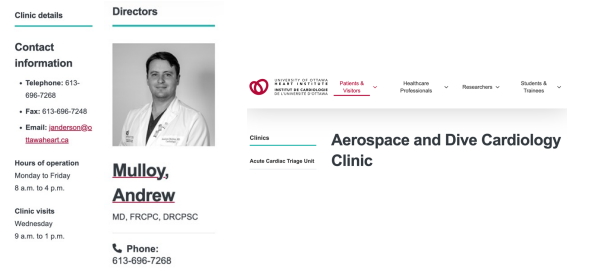

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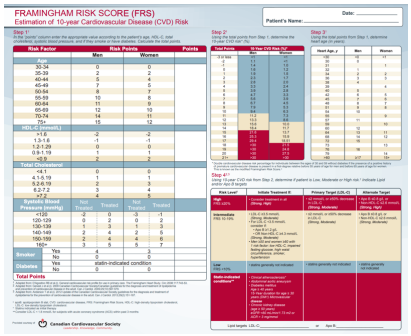

Assess Risks:

Sex
Age
HDL
Total Cholesterol
SBP
Smoker
Diabetes

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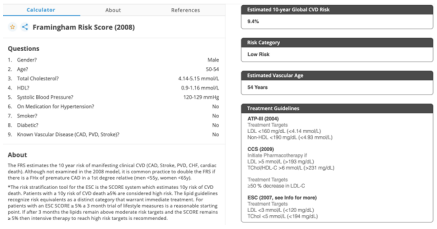
ONLINE CALCULATORS ARE EASY:
https://qxmd.com/calculate/calculator_252/framingham-risk-score-2008



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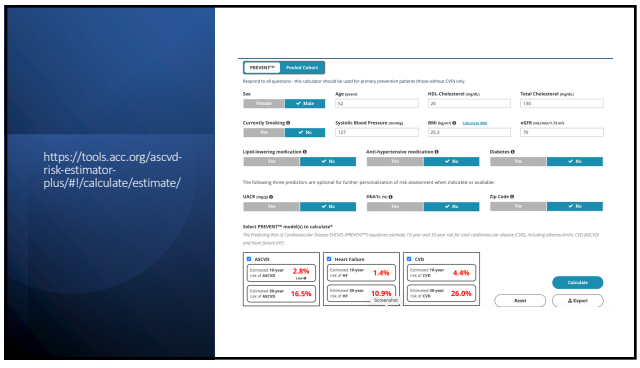

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MET = amount of oxygen consumed at rest
~ 3.5 ml O2/kg/min

- VO2 Max is measured when physical limits are reached
- Peak of VO2 between final 2 exercise work rates, maximal effort achieved and maintained for a specified period (hard to do with cardiovascular or pulmonary disease)
- Maximal effort – VO2 plateau, blood lactate accumulation, maximal heart rate, rating perceived exertion, elevated respiratory exchange ratio (metabolic production of Carbon Dioxide/uptake of oxygen)
- ≥ 1.0 acceptable effort
- ≥ 1.1 excellent effort

$$6\,O_2 + C_6H_{12}O_6 \rightarrow 6\,CO_2 + 6\,H_2O + 38\,ATP$$

$$RER = \frac{VCO_2}{VO_2} = \frac{6\,CO_2}{6\,O_2} = 1.0$$

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Exercise Stress Test

Absolute
- Acute MI ≤ 4 days
- Unstable angina
- Severe symptomatic LV dysfunction
- Dysrhythmias (life-threatening)
- Severe Aortic stenosis
- Acute pericarditis, myocarditis or endocarditis
- Acute aortic dissection

Relative
- Left main coronary disease
- Moderate stenotic heart disease
- Electrolyte abnormalities
- Severe Hypertension > 200/110 mmHg
- Tachy- or Bradyarrhythmias
- Hypertrophic cardiomyopathy or outflow obstruction
- High degree AV block
- Inability to exercise adequately

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Be AWARE this is ESTIMATED not actual

Bruce Protocol – Goal is Stage 4

Bruce Treadmill Test Protocol

Stage	Speed (miles/ hour)	Grade (%)	Approximate Oxygen Cost (ml/kg per min)	Equivalent Ergometer Loads (kilopond-meters/ min per kg body weight)
1	1.7	10	18	7
2	2.5	12	25	11
3	3.4	14	36	16
4	4.2	16	46	21
5	5.0	18	56	26
6	5.5	20	63	30
7	6.0	22	?70	34

Chester Step Test VO2 max > 44 ml/Kg/min, 40-44 short duration or limited

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Chester Step Test

- Strong correlation with VO2 values from treadmill test (r=0.92)
- 5 Levels (15, 20, 25, 30, 35 steps/min)
- 10 minute maximum test
- Heart rate and RPE at end of each level
- Enter data in aerobic capacity software
- Can not use if knee/hip problems or beta blockers
- 10% variability
- Reliable

BORG SCALE OF PERCEIVED EXERTION

6	
7	Really, really easy
8	
9	Really easy
10	
11	Fairly easy
12	Moderate
13	Somewhat hard
14	
15	Hard
16	
17	Really hard
18	
19	Really, really hard
20	Maximum effort

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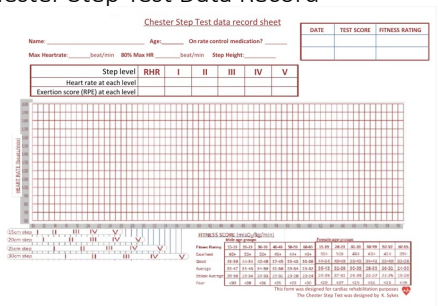
Chester Step Test Data Record



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NEJM Evidence

Published January 28, 2025
NEJM Evid 2025;4(2)
DOI: 10.1056/EVIDra2400390

REVIEW ARTICLE | PHYSICAL ACTIVITY AND EXERCISE SERIES

Cardiopulmonary Exercise Testing

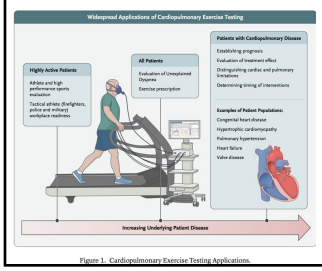

Figure 1. Cardiopulmonary Exercise Testing Applications.

- Assess dyspnea on exertion
- Assesses at submaximal and peak exercise
- Use for us is in older divers who now have valvular disease and we need to assess importance of stenotic or regurgitant lesions
- Treadmill or cycle ergometer

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Return to Diving Post-Malignancy

- ADCI allow return to diving if 5 years post treatment with chemotherapy or ± radiation with no evidence of recurrence
- Watch for:
  - Anthracyclines (Doxorubicin, Daunorubicin, Epirubicin, Idarubicin) the higher the dose received the more likely to get cardiomyopathy
  - Trastuzumab (Herceptin) – Antibody against human epidermal growth factor receptor 2

Many Cancer Therapies cause CARDIOMYOPATHY

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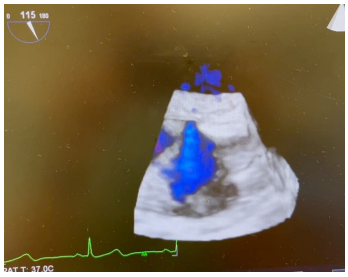
Transeptal puncture > 6 months prior



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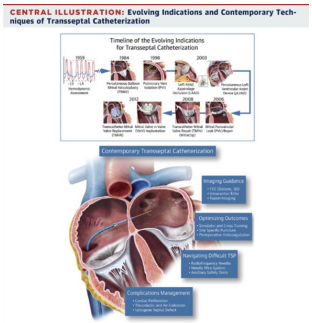
Transseptal Puncture

- Need to be aware of size of hole
- May be used for:
  - Left sided arrhythmia catheter ablation
  - Left AV node ablation
  - Pulmonary vein isolation
  - Transvenous mitral commissurotomy
  - Left atrial appendage occlusion
  - Mitra-clip application
  - Percutaneous Mitral valve

1 French – 0.33 mm

7.5 Fr Sheath = 2.5 mm hole



Alkhouli, M. et al. J Am Coll Cardiol Intv. 2016;9(24):2465-80.

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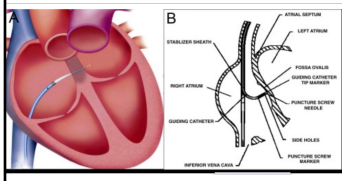
Journal of the American College of Cardiology

Volume 51, Issue 22, 3 June 2008, Pages 2116-2122

Transseptal Puncture Procedures



- Electrophysiology studies
- Percutaneous Mitral Valve Repair
- Left Atrial Appendage closure
- Tandem Heart Left Ventricular Assist device
- Paravalvular leak closure
- Right Carotid stent insertion

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190 Diving and Hyperbaric Medicine Volume 51 No.2 June 2021

Incidence of cardiac arrhythmias and left ventricular hypertrophy in recreational scuba divers

Peter Buzzacott[1,2], George Anderson[1,3], Frauke Tillmans[1], James W Grier[4], Petar J Denoble[1]

- Sudden Cardiac Death 20-30% Scuba Fatalities
- 77 divers, 84 dive trips a total of 677 dives
- 55 divers no pre-trip arrythmias 6.5 have post-trip arrythmia median increase of 1 arrythmia
- 14.5 diver with pre-trip arrythmias had median 1 fewer post-trip, 2.0 had no change, and 5.5 had median of 16 or greater
- **AGE**, not BMI or sex was associated with change in frequency of arrhythmias pre and post dive P=0.02
- RR 2.1 for each additional 10 years of age (95% CI 1.1-4)
- 5 of 60 with imaging had LVH

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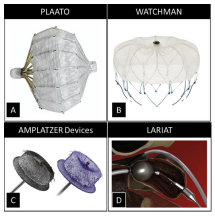
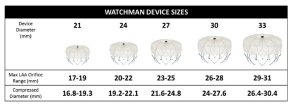
Left Atrial Appendage Occluder Devices





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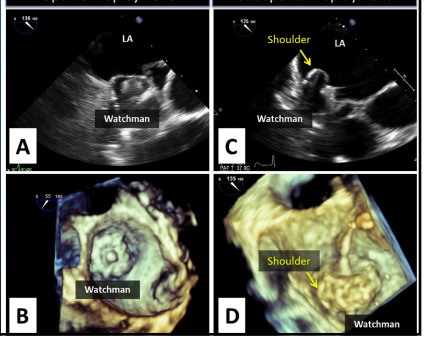
Watchman Occluder Device



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Am J Emerg Med. 2010 Mar;28(3):364-77. doi: 10.1016/j.ajem.2008.12.017.

Myocarditis

- Inflammatory disorder of cardiac muscle, infiltration of myocardium by immune cells and myocyte necrosis
- Focal or diffuse
- Regional or global contractile impairment, chamber stiffening, or conduction system disease
- Variable presentation depending on region involved: chest pain, acute heart failure, or cardiac arrhythmias
- Most common presentation is sinus tachycardia with ST/T wave changes
- In USA (coxsackie virus, parvovirus, and human herpes virus 6) most common
- Diptheria most common bacteria worldwide
- Immune mediated from fungal, protozoal, parasitic, bacterial or viral pathogens
- Autoimmune-mediated etiologies include sarcoidosis, scleroderma, and systemic lupus erythematosus
- Medication related: anthracyclines, cocaine, monoclonal antibodies

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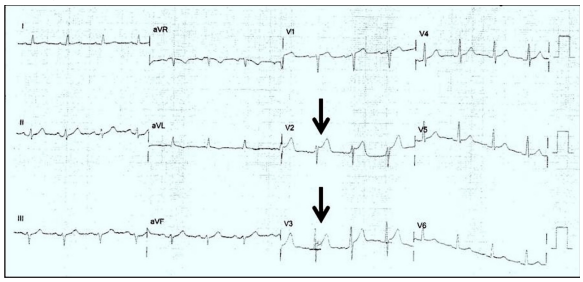
Myocarditis



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Am J Emerg Med. 2010 Mar;28(3):364-77. doi: 10.1016/j.ajem.2008.12.017.

Pericarditis

- Inflammation of pericardium may extend into closely opposed superficial epicardium, an extend to adjacent myocardium
- May result from: infectious causes, autoimmune/connective tissue disease, post myocardial infarction, malignancy, trauma/iatrogenic, toxins.
- Many cases idiopathic
- Chest pain
- Friction Rub
- Widespread ST elevation PR depression
- May have effusion
- ?Echocardiogram
- CT/Cardiac MR

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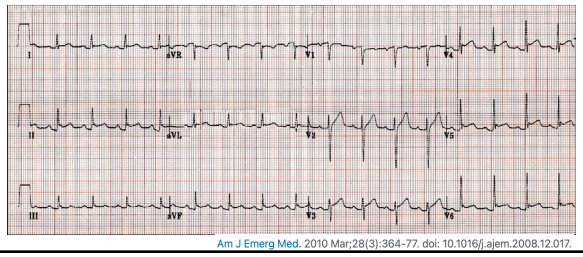
22 yo male, 1/52 post viral illness

Pericarditis



Am J Emerg Med. 2010 Mar;28(3):364-77. doi: 10.1016/j.ajem.2008.12.017.

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Anticoagulation

- Warfain
- Direct Thrombin inhibitors (Dabigatran)
- Factor Xa inhibitors (rivoxaban, apixaban)
- NOT COMPATIBLE WITH DIVING
- (ASA may be acceptable)

Diving and Hyperbaric Medicine Volume 50 No. 3 September 2020

Novel agent	Trial	Intervention versus warfarin unless specified	Number of participants 275 years	Hazard Ratio for Stroke Risk	Hazard Ratio for major Hemorrhage
Dabigatran	RE-LY [10]	Dabigatran 110 mg bid	7,258	0.88 (0.66–1.17)	1.01 (0.83–1.23)
		Dabigatran 150 mg bid		0.67 (0.49–0.90)	1.18 (0.98–1.42)
Rivaroxaban	ROCKET-AF [11]	Rivaroxaban 20 mg bid (15 mg od if eCrCl 30–49 ml/min)	6,229	0.88 (0.75–1.03)[a]	1.04 (0.90–1.20)[a]
Apixaban	ARISTOTLE [12]	Apixaban 5 mg bid	5,678	0.79 (0.65–0.95)[b]	0.69 (0.60–0.80)[b]
	AVERROES [47]	Apixaban 5 mg bid (2.5 mg bid if 2 out of 3 of the following criteria: serum creatinine ≥133 ml/min, age ≥80 years or weight ≤60 kg) vs. Aspirin	1,897	0.46 (0.33–0.65)[b]	1.13 (0.74–1.75)[b]

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Immersion Pulmonary Edema

Or is it just Pulmonary Edema?

- Age > 50 years
- Female gender
- Hypertension
- Over hydration
- Cold Water Exposure
- Physically Trained Endurance Athletes
- Systolic or Diastolic Dysfunction
- Lower lung volumes

Photo: Jill Heinerth

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Coronary Calcium Score

- Coronary calcification occurs concomitantly with progression of atherosclerotic disease (? Smooth muscle apoptosis)
- Usually intimal layer of coronary artery
- Agaston method - Usually breath hold EKG-gated CT scan 2.5 to 3 mm slices
- Area with at least 1 mm3 with density > 130 Hounsfield units
- 0 units - no disease
- 1-99 – mild disease
- 100-399 – moderate disease
- ≥ 400 Agaston units – severe disease

Hazard Ratios
CAC score 101-300 HR 7.7
CAC score >300 HR9.7

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Conclusions:

Contraindications
- Active ischemia
- Functional impairment EF <50%
- Uncontrolled hypertension or end-organ damage
- Right to Left shunt with prior DCS
- Symptomatic Dysrhythmias
- Implantable Cardiac Defibrillator
- Pacemaker
- Moderate/Severe valvular disease

Remember;
- If concerned assess ventricular function
- If concerned get an exercise stress test
- If concerned about HOCM get an exercise stress echo

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Questions?

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